# Clean Water Act Assessment Processes in Relation to Changing U.S. Environmental Protection Agency Management Strategies

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During the 1970s the U.S. Environmental Protection Agency (EPA) devised a multiscale system of basin planning and regional implementation that encouraged a balanced mixture of monitoring and modeling-based assessments. By the 1980s, this goal had not been achieved. Modeling and monitoring assessment approaches became largely decoupled. To a significant degree, modeling was viewed as too inaccurate to handle issues such as setting permit limits involving toxics. During the 1980s, EPA also encouraged the idea that monitoring approaches were adequate to document water quality problems, guide the development of management plans, and demonstrate the achievement of management goals. By the late 1990s, large numbers of waters listed under the Clean Water Act's Total Maximum Daily Load (TMDL) provisions showed the widespread nature of pollutant concerns, but the uneven nature of the listing information also revealed fundamental problems in the ability of state monitoring programs to achieve credible and comprehensive assessments. Statistics are presented from the 1998 and the most current publicly available 2000 baseline periods showing the limitations in the scope of state assessments. There are significant opportunities for the increased use of relatively simple modeling systems that can be flexibly implemented over a variety of spatial scales. In addition to conventional modeling frameworks, the value of bioassessment monitoring techniques is stressed. Bioassessment indicators can often be combined with landscape modeling methods, as well as analyses from conventional modeling outputs, to help target small area monitoring by use of tiered approaches. These findings underscore the value of integrated monitoring and modeling approaches to build properly balanced assessment systems.

## Introduction

Over the past three decades, the Clean Water Act has failed to achieve a productive relationship between its management systems and the assessment systems needed to target major problems and to track the effectiveness of management initiatives. Integration of modeling and monitoring tools in assessment systems is vital to support management systems that aim to address major water quality issues on a watershed basis, but these monitoring and modeling components have, over time, become largely decoupled. This review traces the history of these developments over the last three decades and suggests ways in which modeling systems can contribute to improvements in the identification of water quality problems and the integration of this information in the development of watershed-oriented management initiatives. These improved integrated systems are viewed as critical in achieving meaningful levels of pollution control implementation that match management initiatives to the major water quality needs for hydrologically and ecologically significant watershed units.

The reasons underlying the lack of an effective integration of management and assessment systems are complex, but some major factors can be identified. Under the 1972 Federal Water Pollution Control Amendments (*1*, *2*), the new end-of-pipe technology-based permitting provisions offered a powerful tool to achieve broad-based improvements in water quality conditions even if the infrastructure to pursue management within a larger regional or watershed context was poorly developed. During the 1970s, regional planning efforts were not matched by credible institutions for areawide or basin-level management. The problems in creating the needed management authorities—as opposed to planning functions—under the Clean Water Act were aggravated by the failure during this same time period to pass the Land Use Policy Act (*3*, *4*). This initiative would have energized new federal and state programs under the leadership of the U.S. Department of the Interior and the U.S. Department of Agriculture, leading to a significantly expanded range of federal leverage points for addressing pollution issues related to urban and agricultural land uses.

By the 1980s, the U.S. Environmental Protection Agency (EPA) was increasingly challenged to address water quality-based pollution issues, in many instances related to toxics in effluent discharges. Since end-of-pipe regulatory controls could still be brought to bear to mitigate a large measure of these toxics issues, there was no compelling motivation to integrate issues involving individual discharge permits into a more holistic watershed context. The emphasis on end-of-pipe controls, interestingly enough, also led to a noticeable decline in the use of modeling techniques. The 1987 Clean Water Act Reauthorization revived interest in watershed-based approaches and contained provisions for expanding pollutant permitting to encompass many types of non-point-source problems. It took well over a decade, though, for national regulatory provisions for such urban concerns as combined sewer overflows or urban stormwater runoff to take shape. Efforts during the 1990s to rekindle initiatives for management on a watershed basis advanced slowly and usually aimed to maximize consensus-based techniques since established regulatory tools for non-point-source problems were still substantially lacking.

During the 1990s, a rash of lawsuits related to the Total Maximum Daily Load (TMDL) provisions in Section 303(d) of the Act forced attention on how to apply available assessment information to target water quality-based management efforts (*5*). These 303(d) issues have exposed a number of deficiencies in existing state monitoring and assessment systems, both in terms of the adequacy of these programs to provide comprehensive pictures of the extent of water quality impairments and also in the ability of what are usually rather sparse sets of data to immediately suggest how to develop management systems (*6*–*8*). This review highlights how the increased use of relatively simple modeling

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**TABLE 1. Basin versus Regional Management Features from 1970s Planning Documents**

| geographic focus | major planning and management features |
|---|---|
| basin | develop information on hydrology needed to develop loading effect estimates (models) |
| basin | develop inventories of waste sources (point-source discharges at the very least and, where possible, information on combined sewer overflows, stormwater inputs, and significant non-point contributions) |
| basin | develop screening level load allocation analyses and suggestions for major basin-wide alternatives (the allowable total waste discharges from regional areas could be lumped together as a single discharge) |
| region | take the highly aggregated allowable loading estimates from the basin plans and allocate this allowable discharge among the individual waste sources |
| region | to the degree that the regional area is not a hydrological unit (e.g., a multicounty Council of Governments), make sure that the detailed regional allocations are consistent with the watershed logic of the basin plan |
| region | take into account cost-effectiveness where different allocation options are technically feasible |
| region | develop any needed institutional arrangements necessary for the implementation of the regional plan |

systems that can be flexibility implemented over a variety of spatial scales can promote a better integration of assessment techniques with watershed-based management approaches. These types of modeling frameworks should also be applied in combination with bioassessment techniques and with emerging designs for tiered approaches to assessment that can effectively use combinations of chemical and biological monitoring, watershed-oriented modeling frameworks, and new landscape ecology modeling and analysis systems.

## Management and Assessment Concepts in the 1970s

A review of the evolution of EPA's attempts to supplement the technology-based mandates of the 1972 Clean Water Act (CWA) with the water quality-based approaches that became increasingly important starting in the 1980s leads to a better understanding of how the decoupling of management and assessment systems came about. The 1972 Federal Water Pollution Control Amendments (*1*, *2*) introduced a set of national water quality goals grounded in new institutional provisions as well as institutional expectations. The modern CWA created requirements for point-source dischargers to secure federal National Pollutant Discharge Elimination System (NPDES) permits. These permits established a technology-based floor that generally involved significant across-the-board improvements in effluent treatment. For municipal dischargers, a much-expanded Construction Grants Program paid the lion's share of the costs to put this technology-based foundation in place, and there is little doubt that the NPDES program was effective from both environmental and public health perspectives. Section 208 of the 1972 Act also sought to use the centralized waste treatment systems under the NPDES program as the backbone for a series of regional areawide management agencies (*2*, *9*). At least for urbanized areas, these new management entities were envisioned as addressing both point-source water quality issues and a wide range of non-point-source issues that would often require restrictions on land use practices. Basin-level planning efforts fostered under predecessors of the 1972 Act were also carried over. For instance, Section 303(e) basin planning coordinated through state agencies was expected to drive comprehensive planning efforts outside the larger Section 208 urban area initiatives to target water quality management needs in rural areas.

A variety of federal programs had made use of areawide (multijurisdictional) planning agencies starting in the 1960s. Examples include multicounty or regional planning for highways or urban renewal planning with grants from federal Housing and Urban Development (HUD). Before 1972, HUD grants provided major support for upgrading municipal sewage treatment facilities, and HUD was a primary focus of efforts to provide open-space protection in metropolitan areas. In 1971, HUD and EPA reached agreement on a set of unified guidelines for planning efforts in regard to institutional and intergovernmental arrangements in state, river basin, and regional planning. Under provisions clearly predating the 1972 CWA, EPA set a date of July 1, 1973, for the completion of basin plans (to be developed by the states) and areawide plans to govern actual implementation of upgrades to municipal wastewater treatment facilities in major metropolitan areas (*9*, *10*). This optimistic deadline was not met, and similar deadlines established under the 1972 Act followed a similar pattern of schedules that were not met.

With the passage of the 1972 CWA, EPA aimed to apply information from ongoing basin-wide planning initiatives as the steering mechanism for implementation-oriented tools based on local Section 208 areawide management agencies. EPA capitalized on provisions in Section 303 that provided continuity with initiatives going back to the 1965 Water Quality Act (*10*). Large-scale analyses carried out by state water quality lead agencies were the initial building blocks. By using components from state continuing planning processes (CPPs) such as Section 303(e) basin plans, smaller areas ("segments" within the basins) were identified. Assessments blending monitoring and appropriate models would then be applied to determine segments where baseline controls would suffice. Basin-level screening analyses would also be used in developing a priority list of smaller areas where attainment of water quality objectives required more ambitious technical and localized regional (areawide) institutional management attention.

Different types of arrangements were possible, and EPA developed guidance materials that included a series of case-study examples of how the areawide approach might be applied to achieve the goals of the CWA. In addition to examples from metropolitan areas, where adaptation of existing regional councils of government seemed promising, EPA also made suggestions for nonmetropolitan areas where non-point-source factors such as agriculture might be as significant as point-source discharges (*2*, *11*, *12*).

EPA felt that planning and management efforts should operate on at least two geographic scales. There should be efforts on the level of larger basin hydrological systems, but there would often be the need for a different type of planning at the regional level. The differences in the emphases for these two types of geographical management approaches are summarized in Table 1. These early EPA documents still contain many valuable insights on combining basin-level planning activities with implementation-oriented regional activities. The implications are explored of using regional implementation institutions (e.g., multicounty councils of government) that were not hydrologically defined to pursue implementation measures to complement the larger-scale basin plans. While the emphasis through the 1970s was very decidedly on point-source issues, the basin planning orientation favored had much in common with watershed-oriented frameworks that reemerged in the 1990s.

## Loss of a Watershed Focus during the 1980s

While the 1980s witnessed an increase in the application of water quality-based principles, most management actions were still pursued on a highly site-specific, permit-by-permit basis (*13*). There were limited opportunities in most major programs to pay attention to the integrated effects of these site-specific management actions over larger geographic units or watersheds. A major reason for the decline of regional and basin planning was the erosion in the federal funding sources that had nurtured such planning perspectives during the 1970s. This took place against the failure in the 1970s to pass the National Land Policy Act (*3*, *4*), which seriously compromised efforts of individual agencies such as EPA to require states to establish regional governmental systems that placed restrictions on land use practices. The early 1980s saw the collapse of earmarked federal funding for both Section 208 areawide planning and 303(e) basin planning activities. As a result, these systems were progressively weakened (*14*). There were no truly major "midcourse corrections" in the CWA itself in the early 1980s. The basic provisions remained focused on persistent end-of-pipe concerns. For much of the 1980s, the main challenge facing the Office of Water was how to move National Pollution Discharge Elimination System (NPDES) permitting beyond the stage of "best professional judgment," particularly in setting appropriate controls for toxics. Most of the modeling approaches developed in the 1960s and 1970s were not well equipped to handle impacts from toxics (*6*, *15*, *16*). As concerns increasingly focused on the low concentration levels needed to protect aquatic life from chronic toxicity or to address human health concerns from cancer risks, older models geared mostly to simulating toxics at acute exposure levels proved of limited value. By the late 1980s, the vast majority of NPDES permit renewals were addressing both federal and state water quality-based requirements. With the 1987 Clean Water Act Reauthorization and Amendments, greater emphasis was also placed on addressing a variety of other pollution concerns from stormwater, combined sewer overflows (CSOs), and diffuse non-point-source pollution related to both urban and rural land uses. Controlling non-point-source pollution was also reaffirmed as a major goal of the CWA, to join the longstanding goals of reducing pollution from conventional end-of-pipe municipal and industrial discharges. But the 1987 Reauthorization contained no significant regulatory requirements for non-point-source control outside urban areas, and the new programs for urban wet-weather permitting have taken over 10 years to develop.

Under legal pressures to ratchet down NPDES controls below acute toxicity thresholds, EPA came to rely very heavily on static bioassay approaches (*15*). As these tests (commonly referred to as whole effluent toxicity or WET tests) became routine by the late 1980s, there was a tendency among permit writers to give up on older types of modeling systems. The success of laboratory-based bioassay techniques to help in setting point-source permits for the control of toxics encouraged the use of more general-purpose biological analysis tools based on ambient water collections. New monitoring approaches based on both bioassays and bioassessments (*16*) were proposed to determine whether water quality goals were being attained and whether management measures were performing as expected. Bioassessment approaches were helpful in resolving permitting issues for toxics, but bioassessment indicators could also provide clues to help in identifying traditional water chemistry stressors as well as more general pollution concerns such as habitat condition.

The early to mid-1980s witnessed a growing awareness that traditional water chemistry-based monitoring had limitations in demonstrating whether aquatic ecosystems were in good health. Methods to assess biological integrity offered a way to address the full range of factors impacting the health of aquatic communities, which can involve conventional physical and chemical features, the absence of toxicity, and the presence of needed habitat conditions (*17*–*20*). By the mid-1980s, EPA launched a series of major environmental monitoring policy initiatives (*21*). For water quality programs, the enthusiasm underlying these efforts is reflected very strikingly in a report commonly called the Framework document (*22*). A grand vision was presented that would meld new capabilities in toxic bioassays and biological monitoring with older approaches to produce comprehensive, and technically sound, assessments of water quality status and trends.

While there was great promise in these new techniques (*23*), the degree to which the states and EPA were able to apply these types of sophisticated assessment techniques proved to be very uneven. States such as Ohio (*24*) and Maryland (*25*) that started serious efforts to build biological assessment programs during the 1990s now have powerful assessment tools, with information available to document conditions within fairly small watershed areas and to support sophisticated upstream–downstream analyses to help pinpoint the pollution causes and stressors related to poor biological conditions. An illustration of the power of such biological monitoring information when integrated with other modeling and landscape ecology tools is documented in a recent synthesis of work in Ohio's Auglaize River system (*26*). The methods now established for Ohio's assessment program can document impairments related to typical chemical or physical impairments and can also take into account a more comprehensive array of pollution factors (e.g., altered flows, changes in physical habitat, or the presence of alien taxa such as noxious plants).

In most states, however, monitoring programs were less well developed. EPA's expectations in the 1980s (*27*) were that state monitoring and assessment programs should be adequate to pinpoint major pollution problems in areas showing poor conditions in terms of major fishable–swimmable water quality standards and other designated uses and to provide enough information on underlying pollution causes and stressors to suggest the broad outlines of needed management measures. As became progressively apparent from the late 1980s and into the 1990s, the available information from the states was frequently inadequate to lead directly to well-grounded management plans. For instance, situations were common where bioassessment indicators for the aquatic community condition scored very poorly in relation to a set of target reference conditions. The poor biological conditions could be the result of stressors involving conventional chemical or physical parameters (e.g., depressed dissolved oxygen from the introduction of inadequately treated sewage effluent), toxics, or problems related to habitat (e.g., loss of riparian vegetation, alternatives in flow regimes, or alternatives in substrates from channelization). Without additional studies, however, it could be difficult to determine which factors were involved in a poor indicator score, and without this additional information, developing any immediate watershed or site-specific management responses would not be feasible.

While the 1980s witnessed the showcasing of new approaches to improve the quality of monitoring programs, this decade also marked the beginning of a steady decline in the fixed-station ambient trend monitoring networks established during the 1960s and 1970s. The steady erosion in the number of gaging stations in traditional fixed-station networks has been well documented in a special U. S. Geological Survey (USGS) Report to Congress (*28*). This same USGS document shows that nearly a thousand gaging stations were discontinued in the period from 1978 through 1988. The loss of gaging stations was accompanied by disruptions in sampling efforts to gather water quality data (*29*). Major

reorganizations of the USGS cooperative programs with the states in the early 1980s often led to serious interruptions in fixed-station water quality data collections.

Given the large number of data gaps in the available monitoring-based assessment information, appropriate modeling tools could have done much to help put site-specific monitoring results into a broader geographic and hydrographic perspective. But in fact large-area modeling, or almost any sort of nontrivial watershed modeling, was virtually abandoned by EPA and the states by the end of the 1980s. The idea became widely accepted that a set of management measures that seemed appropriate to a given problem should be applied and then success could be documented through data collected from a fairly sparse monitoring network. This concept of anchoring assessment programs almost exclusively on monitoring has met with very mixed success, especially where the monitoring efforts lacked suitable experimental designs. Even with the probability-survey approaches (*30*) championed through the EPA's Environmental Monitoring and Assessment Program (EMAP), landscape-level status and trend indicators (typically for aquatic ecology features) reflecting areas such as whole states or large basins will shed little light on more localized conditions for small watersheds or specific stream reaches.

While EPA's Office of Research and Development is working on ways to link information on broad-scale indicators with information dealing with site-scale conditions (*31*), the needed techniques are still being prototyped. A typical problem is that the available information, even when probability-based sampling designs and biological indicators are used, will simply provide indicators of condition, and this for relatively sizable areas. Additional information is needed to suggest likely causes and stressors. EPA is now encouraging the application of landscape ecology-based analysis techniques. In EPA's Mid-Atlantic Integrated Assessment (*32*, *33*), geospatial analyses established the causal relationships between watershed characteristics and nutrient and sediment loads. By use of GIS landscape metric data combined with nutrient (nitrogen and phosphorus) and sediment data, several landscape metrics showed strong correlations with nutrient and sediment loadings on a set of watersheds in the Chesapeake Bay basin. EPA uses the terminology "landscape modeling" for these sorts of geospatial approaches. For states that lack the depth of the well-established programs available in the Ohio or Maryland programs, such techniques applied over large landscape units can support tiered approaches that can then help target more intensive monitoring efforts for small watershed units.

Clearly, conventional water quality modeling techniques can also contribute to such tiered approaches. The challenge for an assessment process based on sparse monitoring networks charged with determining management program effectiveness is that the confident documentation of improvements usually requires substantial changes in either pollutant concentrations or loadings. A classic example is the 40% nutrient reduction target for the original Chesapeake Bay program strategy. If the performance goals are set much lower than a 30−40% reduction target, then a balanced toolkit involving management inventories, well-designed monitoring networks, and appropriate modeling can be invaluable to confirm that an aquatic system is responding as anticipated to implementation measures. Without the additional analytical tools provided by modeling, documentation of trend patterns based on fixed-station monitoring techniques alone could require data collections taking decades (*34*, *35*). Appropriate biological monitor techniques could help provide alternatives for extensive collections of time series of chemical parameters (*26*), but water quality models can also be of considerable value.

An example of such approaches based on water quality models can be drawn from activities supported through work on the Great Lakes in the United States and Canada. Of particular interest is work related to non-point-source pollution abatement efforts conducted through the Pollution from Land Use Activities Reference Group (PLUARG) for the Water Quality Board of the International Joint Commission (*36*). PLUARG produced numerous technical documents from the start of the 1972 Great Lakes Water Quality Agreement (GLWQA) leading up to recommendations for the 1978 renegotiation. Most of this work was anchored on the initial GLWQA focus on the control of phosphorus nutrient loadings, but these efforts also branched out to studies of other toxic non-point-source-related pollutants that became the primary concern of the GLWQA during the 1980s and 1990s.

PLUARG was able to tap information from several watershed-level agricultural demonstration projects, a growing database (especially for Lake Erie) of tributary loadings to the Great Lakes, and other point-source and urban non-point-source activities in both the United States and Canada. Prototypes were at least outlined—and implemented for some watersheds—suggesting how to build comprehensive management frameworks that included modeling, water quality monitoring, and other tracking tools. The focus was on nutrient control, but PLUARG looked at other pollutants and pollution issues (e.g., pesticides). The PLUARG umbrella helped nurture the early work of James Karr with biological assessment metrics on Black Creek in Indiana, and the Black Creek studies were also critical in the development of continuous simulation models such as ANSWERS (*37*). The work of Karr clearly showed the value of good monitoring data related to aquatic community health as a way to make sure modeling systems included major features (e.g., impacts from ditching and draining and loss of riparian habitat) reflected in the performance of his IBI (Index of Biological Integrity) bioassessment metrics. Ideas from PLUARG helped give focus to the EPA National Urban Runoff Project (NURP) studies of the late 1970s to early 1980s (*38*). The legacy of PLUARG was great; it demonstrated that measures beyond end-of-pipe phosphorus control for point-source discharges would be needed to reach desired nutrient loading reductions for the Great Lakes.

One feature in the Great Lakes nutrient control initiatives that differs from the patterns found in many estuarine systems (e.g., Chesapeake Bay) is that the Great Lakes nutrient reduction targets were often set at values less than 20% of the original annual average baseline levels. For ambient monitoring designs to document confidently these modest loading reductions, it might take 20−30 years in light of substantial natural variability in weather-driven runoff (*36*). For many estuarine systems such as the Chesapeake Bay where nutrients are a concern, target reduction levels of 30% or more are more typical. A major consideration in setting such high performance goals is that reductions significantly greater than 20% are needed so that even 10 years of monitoring data will document improving trends in nutrient loads. For the Great Lakes, there were pressures to keep the nutrient loading reduction targets as low as possible. Without the luxury of a significant margin of safety to tack onto the nutrient reduction targets, it was vital to have numerical estimates from screening models to have confidence that the proposed management implementation measures could meet the goals. To give indicator signals over a shorter time frame, PLUARG recommended that nutrient management measures be tracked by watershed unit. Best Management Practices (BMP) tracking and monitoring work were also to be compared with modeling estimates. The BMP tracking would be a "programmatic" indicator. This would become a surrogate for indicators based on actual environmental measurements (chemical measurements, flows, loading

estimates, and also biological indicator results). These concepts are highly relevant to present concerns under the Government Performance and Results Act (GPRA) that EPA often places too much reliance on simple output measures instead of outcome measures tied more directly to environmental conditions (*39*).

With the shift in focus to toxics control after the 1978 GLWQA renegotiation, the PLUARG approaches with their emphasis on nutrients fell out of the limelight. Only in the past few years (*40*), on the 20th anniversary of the formal completion of the PLUARG project, has the value of such balanced approaches been rediscovered as efforts to control impacts from nutrients and sediment have once again come to center stage. The way the PLUARG work fell into obscurity during the 1980s was indicative of the steady unraveling of basin and areawide planning. Concepts such as intensive surveys to help tune regional-scale models and the use of models to make extrapolations and help fill in the inevitable gaps from sparse monitoring networks languished. It was against this backdrop of the virtual disappearance of the idea of basin-oriented continuing planning processes that EPA in the early 1990s started to re-emphasize management approaches organized around watersheds.

## Regaining an Integrated Watershed Perspective

EPA's watershed-oriented initiatives in the early 1990s attempted to avoid an exclusive reliance on regulatory approaches. Many of EPA's efforts were designed simply to document the benefits of planning and management efforts organized around watershed units and to progressively change the mindsets and cultures of agencies and programs at the federal, state, and local levels that usually showed very little attention to integrated, holistic approaches geared to ecological and public health outcomes for large geographic areas (*41*). Many of the established geographic or community-based approaches were based largely on consensus. This included geographically large examples such as the Chesapeake Bay down through much smaller examples from Section 314 Clean Lakes restoration projects geared to the watersheds of small natural lakes or reservoirs featuring public recreational amenities. EPA devoted considerable effort to change the "culture" in such pivotal programs as NPDES permitting. Incremental enhancements took place in the Section 319(h) grant program to encourage watershed-based as well as statewide approaches to non-point-source management. Efforts to coordinate the mitigation of urban or rural non-point-source problems with the control of similar pollutants under the traditional NPDES programs were encouraged (*42*). EPA promoted rotating basin systems as a method for state permitting agencies to organize their work processes around well-defined watershed units. Instead of conducting a full range of management services such as monitoring and permit writing over an entire state each year, a state could be broken into a convenient number of large planning basins. A rotating system could allow management activities to focus efficiently on just a few basins each year. Over approximately a 5-year period, major management service activities would have rotated through all the basins, and the cycle would then be repeated.

EPA also took advantage of provisions in the 1990 Coastal Zone Act Reauthorization Amendments (CZARA) to develop extensive documentation on the effectiveness of "management measures" (or BMPs) to address a range of rural or urban non-point-source pollution issues. Many elements from these original estuary- and coastal area-oriented CZARA management measure handbooks (*43*) have been updated to cover non-point-source issues for all parts of the country [e.g., the national management measures for recreational marinas (*44*)]. These efforts in EPA's Office of Wetlands, Oceans, and Watersheds also benefitted from the development of information systems on the effectiveness of management controls to handle a range of stormwater, confined animal feeding operations, and other NPDES-related initiatives anchored in the Office of Waste Management (*45, 46*).

The early 1990s witnessed a series of special initiatives within EPA to ground federal and state management efforts on major ecological or public health problems for individual "places." Consensus-based approaches were pursued to broaden the stakeholder base and achieve agreement on management objectives. While care is needed in such consensus-based approaches to ensure the equitable representation of the full stakeholder community (*47*), EPA's major concern in the early 1990s was simply to organize place-based or community-based initiatives under the concept of watersheds (*41, 48−50*). There were several variants of this "watershed approach" concept within the Office of Water, with these approaches sharing many traits in common with ecosystem management frameworks pursued by EPA's Office of Research and Development, EPA's Office of Policy (*51*), and other federal natural resource agencies. Within the Office of Water, considerable effort was directed at encouraging states to reinvent, using new terminologies and new risk management concepts (*52*), what amounted to the basin planning and continuing planning process mechanisms that had fallen apart during the 1980s. A major incentive for the Office of Water was to breathe life once more into what had become little-used legal requirements under the Clean Water Act and existing regulations related to Title III provisions under Section 303(d) dealing with total maximum daily loads (TMDLs).

The Pacific Northwest was the focus of a series of TMDL lawsuits that started moving through the federal district courts in the late 1980s. In these initial TMDL lawsuits, the aim was often to use CWA Act provisions to force better implementation of federal and state forest management practice laws. Given the special local overtones in many of these initial TMDL lawsuits, it was not clear that the federal court rulings established national precedents. A case involving Georgia, however, turned TMDLs into a nationwide issue (*5*).

By 1996, all states were under pressure to develop listings of waters that needed TMDLs. The main source of information to develop these lists was the materials states had assembled as part of their Section 305(b) reporting efforts. By the completion of the second significant 303(d) listing cycle in 1998, serious questions were being raised about the reliability and precision of these listings, and such questions naturally raised concerns about the credibility of the 305(b) process (*53, 54*). The primary problem with the current 305(b) process is that it represents a compendium of "readily available information." The underlying monitoring and survey materials used to create 305(b) assessments, and Section 303(d) listed waters, also tend to be very site-specific. Some of the monitoring data are of reasonably high quality, while other information is either dated or based on materials that may have severe limitations. In making their waterbody assessments, states typically wind up with a set of site-specific conclusions not based on any common underlying experimental designs.

Even more fundamental than the lack of sophisticated monitoring strategies is the fact that the nature of most 305(b) assessment information, and also most 303(d) listing materials, makes it very hard to organize the problems according to logical ecological or hydrological units. On the basis of information from a wide range of different programs, states have logged concerns in their lists, usually trying to define the spatial extent of the problem as a small vicinity around a data collection or monitoring point. EPA's current backlog of 303(d) listings clearly did not typically flow from well-institutionalized basin- and watershed-based planning and management programs. One solution to these TMDL

**TABLE 2. Summary Statistics on the Percentages of River Miles Assessed in USGS Cataloging Unit Watersheds for Different Assessment Level Targets[a]**

| targets[b] | assessed river miles meeting target (%) | | | |
|---|---|---|---|---|
| | 1998[c] | 2000[c] | 1998[d] | 2000[d] |
| at least 25% of the rivers in CUs assessed | 65 | 84 | 24 | 62 |
| at least 50% of the rivers in CUs assessed (median level of effort) | 38 | 69 | 10 | 50 |
| at least 75% of the rivers in CUs assessed | 23 | 60 | 2 | 44 |
| mean level of assessment for a CU watershed | 45 | 72 | 20 | 55 |

[a] Statistics based on an analysis of river waterbodies from EPA's National Assessment Database (NAD) for 1998 (assessments from 1240 USGS CUs in the conterminous United States) and EPA's NAD for 2000 (assessments from 1361 USGS CUs in the conterminous United States). [b] Targets for levels of assessment for the 1998 and 2000 305(b) baseline periods. [c] Relative to perennial stream miles. [d] Relative to total (perennial + nonperennial) stream miles.

issues is undoubtedly to move as rapidly as possible to integrated information and management systems organized around well-defined geographic units. Initially, though, the enormous quantity of 303(d) listings inherited in the late 1990s has made it hard to see the "forest" of a watershed for the "trees" of the individual 303(d) listings. Over the short term, it could be argued that the TMDL process has likely delayed the development of meaningful watershed-based approaches. On the other hand, TMDL issues have been an important wake-up call showing that a large portion of the nation's waters are not attaining the Act's fishable/swimmable goals, and that while the stressors involve pollution issues of all types, the most common impairments are from such traditional pollutants as nutrients, sediment, and pathogen indicators. Over the long term, the challenge is to persist in efforts to build the needed institutional and information infrastructures to make these systems work. In building the needed assessment information systems, it has become apparent that monitoring by itself is unlikely to provide all the tools needed to document problem areas or to suggest appropriate management solutions.

The highly site-specific CWA assessment conclusions have tended to become points of light in a hydrographic network that is often 50% or more nonassessed. In processing 1994 305(b) data for the initial release of EPA's Index of Watershed Indicators (*55*), river assessment information was organized by USGS eight-digit cataloging unit (CU) watersheds (CU watersheds are also now referred to as "subbasins"). Less than half the Index of Watershed Indicators (IWI) watersheds showed levels of assessment effort that would account for at least 50% of the perennial stream miles in each CU. If the assessed river miles were compared with estimates of total stream miles by watershed, then only about 10% of the CUs would show assessments for even half the total river miles by watershed.

The water quality standards attainment indicator originally developed for the IWI is still used as the basis for an Office of Water and Performance Results Act (GPRA) outcome measure. Table 2 provides summary statistics based on EPA's National Assessment Database for 1998 and 2000 used in preparing the GPRA indicators of watershed use attainment status presented in EPA's Annual Reports for Fiscal Years 2001 and 2002 (*56*, *57*). These materials show information on assessment level-of-effort percentiles relative to perennial river miles or total river miles for USGS eight-digit CU watersheds. The CU-based perennial and total river miles estimates are based on information in EPA's Total Waters Database (*58*). These GPRA outcome measures reflect what states have reported in their Section 305(b) databases used to construct the Office of Water's National Assessment Database (NAD). Statistics for inland river waterbodies from the NAD can provide robust information regarding the level of state assessment effort over the past several reporting cycles.

The 1998 305(b) baseline period results are very similar to the findings used in the IWI based on 1994 305(b) baseline information. The median assessment level for rivers accounts for 38% of the perennial river miles in CU watersheds. Relative to combined perennial and nonperennial stream miles, however, this 1998 median level of assessment effort still reflects only about 10% of the total river and stream miles for CU watersheds in the conterminous United States. Increases in assessment effort are reflected in the year 2000 figures. The 2000 results show the median assessment level for rivers increasing to around 69% for the perennial river miles baseline target and with a median assessment level of 50% for total river miles as the baseline target. These figures are based on all available assessment information from river waterbody assessment units used to develop the GPRA measures.

The figures presented in Table 2 combine assessments for individual river waterbodies with different levels of precision and reliability in types of monitoring data or other survey information used to draw the assessment conclusions. Through the 2000 cycle, EPA's 305(b) reporting process included a method allowing states to rate the assessment quality of each waterbody as either "monitored" or "evaluated." Assessments based on "monitored" information would typically include findings derived from recent sampling or field work involving chemical, physical, or biological data. Assessments based on "evaluation" information would include the results of modeling simulations, inferences from land use inventories or remote sensing data, records on permit violations (which may involve very high quality bioassay test results), and older "monitored" information that could be used to look for water quality degradation trends. Evaluation information would also be a major tool to make determinations on the sources (e.g., point-source dischargers or non-point-source land uses) constituting the stressors leading to the water quality impairments. For the 1998 baseline period, about 54% of the river miles assessed were characterized as being of a "monitored" assessment quality; by 2000, the monitored river miles had increased to a level of 61%. These national levels of "monitored" assessment quality can vary widely from state to state. Given the concerns voiced in numerous studies over the potential for errors in "evaluated" assessments, many states began to trim nonmonitored conclusions from their 305(b) assessment results by the 2000 305(b) cycle. Still, based on analyses of NAD 2000 data from 35 conterminous states, 80% of these states showed some use of evaluated assessments; 28% of the states depended on evaluations for at least 50% of their river miles assessed; and 17% of the states depended on evaluations for up to 75% of their river miles assessed.

While there has been progress in the period since 1994 in increasing the level of assessment effort and even in increasing the sophistication of the assessment methods used to reach use attainment decisions, a large percentage of the nation's river miles still lack any type of recent assessments. The lack of information to directly assess more than perhaps 50% of the nation's rivers and streams leaves enormous data gaps, and similar data gaps exist for nonriver waterbody types

(e.g., lakes and estuaries). If stringent levels of quality control reliability and precision were applied to the available data, then the typical level of assessment would likely drop to well under 50% of the nation's waters. Improvements in the comprehensiveness and the quality of assessments will require greater care in the design of monitoring networks. But improvements should also be pursued in the area of nonmonitored assessment tools, which should entail the more careful application of modeling and decision support systems to supplement the monitoring results.

## Discussion

The present review has stressed the importance of better integration between monitoring and modeling systems in developing watershed-oriented solutions for problems related to ubiquitous 303(d) pollutants such as nutrients, sediment, and pathogens. In a set of proposals to the Office of Water on how EPA's Office of Research and Development could provide new tools for these TMDL challenges (*31*), there is an awareness that resource limitations will likely preclude the application of highly complex assessment projects to every watershed in the country. To provide adequate information products for decision makers, the resources devoted to monitoring—and related management analyses—will likely need to be increased. For instance, a recent analysis of data needs necessary to apply even the simplest of statistical tests to identify small watersheds or individual water bodies with water quality standards nonattainment suggests that status and trends monitoring efforts need to be expanded in one mid-Atlantic state by at least a factor of 2 (*59*). Similar desirable levels of resource increases are mirrored in a recent national analysis of resource needs for state monitoring and assessment programs (*60*). Well-designed bioassessment systems, and other carefully targeted monitoring designs, can often achieve significant efficiencies in providing the needed assessment information (*26*). The effective application of a full range of integrated tools, including modeling, can augment the available monitoring information to build more flexible and powerful integrated assessment systems.

To target management efforts and track management success, the need for improved assessment systems is obvious. Implementing these enhancements given the general condition of state monitoring and assessment programs through the late 1990s, however, presents major challenges. Comprehensive monitoring of all waters, in the sense of immediately performing credible monitoring work on every waterbody, seems unattainable. In most states, the problem is how to start from monitoring signals that are not comprehensive to build a fuller picture of the spatial distribution of water quality problems and the underlying causes and sources. Modeling approaches can be helpful, especially for a range of chemical or physical pollutants that dominate the current 303(d) listings. The focus in this review has emphasized conventional models applied on a regional or watershed basis, but other types of "landscape" models are also relevant (*33*). These modeling approaches should be coupled with innovative monitoring techniques, especially bioassessment approaches, as part of tiered assessment systems.

Complications in establishing meaningful implementation programs in light of EPA's limited regulatory powers under the Clean Water Act also persist. During the 1990s, the need to tackle water quality problems by use of a more holistic watershed-oriented framework became compelling from a policy perspective, and the TMDL lawsuits have forced EPA and the states to make serious efforts to move beyond the stage of policy and planning. EPA and the states have a broader range of NPDES-related tools, especially for wet-weather issues in urban areas. Watershed-based permits are now being issued where the pollution concerns relate to regulatory controls involving traditional end-of-pipe or new types of wet-weather concerns. The next step will be to establish credible watershed-oriented management frameworks that combine regulatory and other types of more consensus-based control arrangements. EPA has established policy guidelines for these type of water quality trading initiatives (*61*), and such new regional and watershed-based management approaches must aim to achieve a better degrees of integration with assessment systems than has been the case over the previous 30 years. This review leads to the recommendation that the anchor of effective management programs at the federal level should be these watershed-oriented permitting and trading systems. The federal NPDES program must almost of necessity become the backbone for creating meaningful watershed-oriented management institutions and provide the major impetus for associated assessment systems.

The ultimate challenge in addressing the typical 303(d) listings of problem waters representing small vicinities around monitoring stations is to relate these "hot spots" to what is happening in larger watershed units. As a National Research Council study in the early 1990s stressed (*62*), a major shortcoming in many EPA programs was that funding limitations tended to limit projects to demonstrations covering extremely small spatial units. Ecologically meaningful management interventions must usually trigger changes in watershed units at least on the scale of the USGS eight-digit CUs (subbasins) to have any significant consequences. As emphasized in a number of recent studies (*6*, *50*), assessment systems are needed—involving monitoring as well as other tools—that can provide insights for such watershed-scale spatial areas.

A reporting logic based on spatial units that are simply small vicinities around monitoring stations seriously complicates making watershed-level inferences about impacts from specific pollution causes or sources. Especially where there is any appreciable wet-weather (non-point-source) dimension to the water quality concern, being restricted to a virtual "peephole" on a short reach of stream makes it difficult to determine the prevalence of stressors or the sources of these stressors over a large landscape unit. Additional analysis efforts, incorporating both well-designed monitoring network assessments and significantly upgraded screening modeling systems, are needed to regain a vision of the forest from the trees of at least 20 000 individual TMDL listings.

The development and implementation of modeling and decision support systems for watershed units of virtually any size is now considerably simplified as standard hydrological data systems such as the USGS's National Hydrography Dataset become available (*63*, *64*). One such system is the National Water Pollution Control Assessment Model (NWPCAM). NWPCAM (*65*) was originally developed by EPA for risk—benefits analyses for new regulations and effluent guidelines. It can be easily adapted for establishing TMDLs and in examining pollutant reduction alternatives involving watershed-oriented NPDES permitting for multiple discharges or more complex pollutant trading arrangements involving both NPDES permits and less stringently regulated non-point-source land uses. Its origins as a tool for costing regulatory alternatives allows the NWPCAM to be implemented as part of a risk—benefits decision support system to help stakeholders examine the pros and cons where a given pollutant reduction target could be achieved by a variety of different source allocations over a watershed unit. Fate and transport modules of varying degrees of complexity can be integrated into the NWPCAM. In its simplest mode, the NWPCAM provides a robust screening model to provide estimates geared to annual average or seasonal flow regimes

for such common TMDL pollutants as sediment and nutrients. More complex fate and transport modules, including WASP (Water Quality Analysis Simulation Program), can be introduced where appropriate to handle problems encountered with lakes and estuaries (*66*). NWPCAM, as with most modeling systems, helps relate excessive levels (in terms of concentrations or loadings) of pollutants to probable pollution sources. Any initial identification of stressors always merits additional scrutiny to ensure that the source attributions to particular human activities are credible and that major sources for critical pollutants have not been overlooked. By forcing attention on sources, however, models help in linking pollution causes and pollution stressors to provide the foundation for a complete management system (*6*). Adding this expanded range of assessment capabilities to water quality programs from modeling frameworks would do much to help institutionalize the multiscale watershed assessment and management approaches that were major goals of the 1972 Clean Water Act.

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